4. RESULTS AND DISCUSSION: WATER QUALITY

PHYSICAL CHARACTERISTICS

Temperature, Salinity, and Oxygen Content

A summary of the 1974 annual variations at the surface and bottom in temperature, salinity, and oxygen content are presented in Figs. 4-1, 4-2 and 4-3. The simultaneous changes in subsurface content of dissolved oxygen and salinity as a function of time at the four sampling stations are shown in Fig. 4-4. These relationships are given for two depths at each of the deep stations and for the bottom only at the other two stations.

With two exceptions, to be mentioned below, the general trend was the same at all four locations. Salinity and oxygen values remained relatively constant (ranging from .000 to .072 S‰ and 9.5 to 12.6 mg O_2/l until early July). At that time, coincident with a significant drop in wind speed (Fig. 4-5), oxygen levels began to decline rapidly; in one month they fell to within about 1 mg/l of the annual minimum near bottom at Stations 518, 522 and 532.

The decrease in oxygen concentration at 10 m at the deep stations (522 and 532) and at the bottom at the midlake station (526) was somewhat less dramatic, probably because of continued influence from surface wind.

Note that before early August, salinity increases at these depths were minimal. The lake was undergoing stratification and had reached a nearly anoxic state in the deepest parts before any major saltwater intrusion.

The effect of temperature on the stratification process is suggested by Fig. 4-6. Bottom temperatures at all stations increased to near annual maxima, whereas O_2 concentrations approached annual minima before any significant increases in salinity. It is therefore evident that the initial stratification of Lake Union is primarily controlled by temperature and secondarily by the intrusion of saline water from the Chittenden Locks. In the same sense, the extensive depletion of oxygen in the hypolimnion by the decomposition of oxygen-demanding substances is only marginally influenced by salinity. This contention is further supported by data obtained by Metro for the period 1964-1970 (Fig. 4-7); they show substantial drops in dissolved oxygen levels at Station 532 prior to any significant increases in salinity in 1965, 1967, 1969, and 1970.

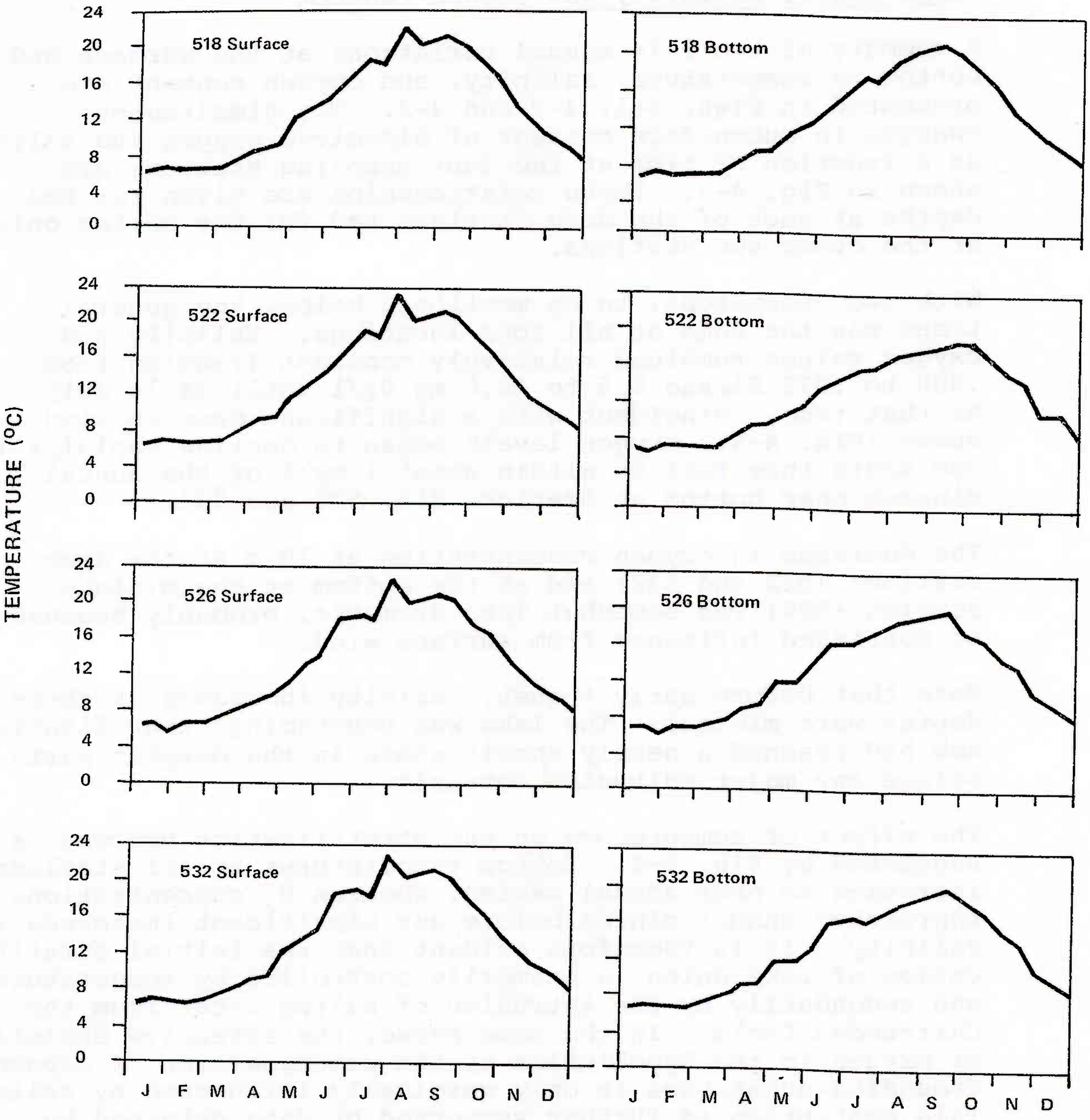


Fig. 4-1. Temperatures at the surface and bottom of Lake Union, 1974.

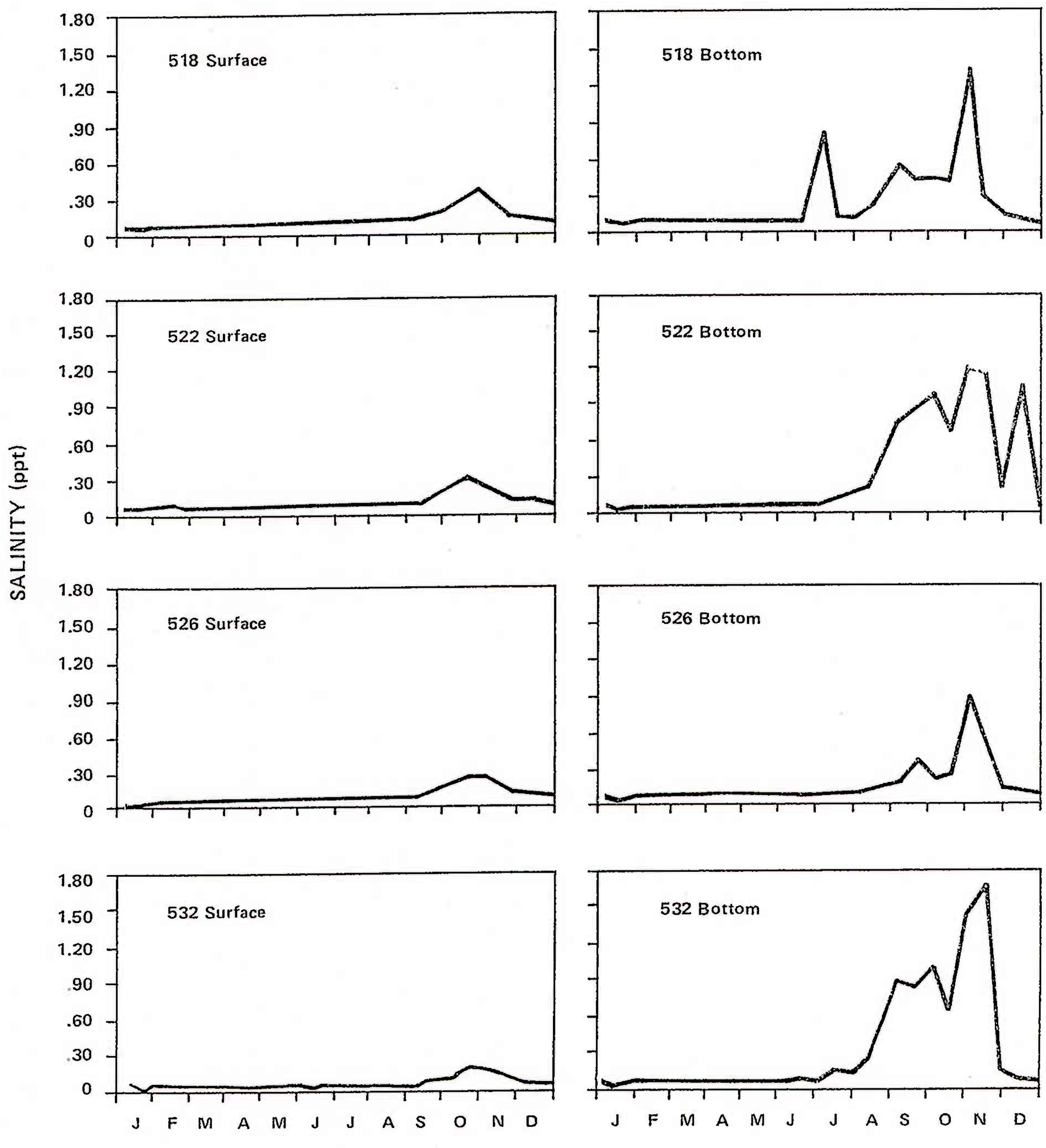


Fig. 4-2. Salinities at the surface and bottom of Lake Union, 1974.

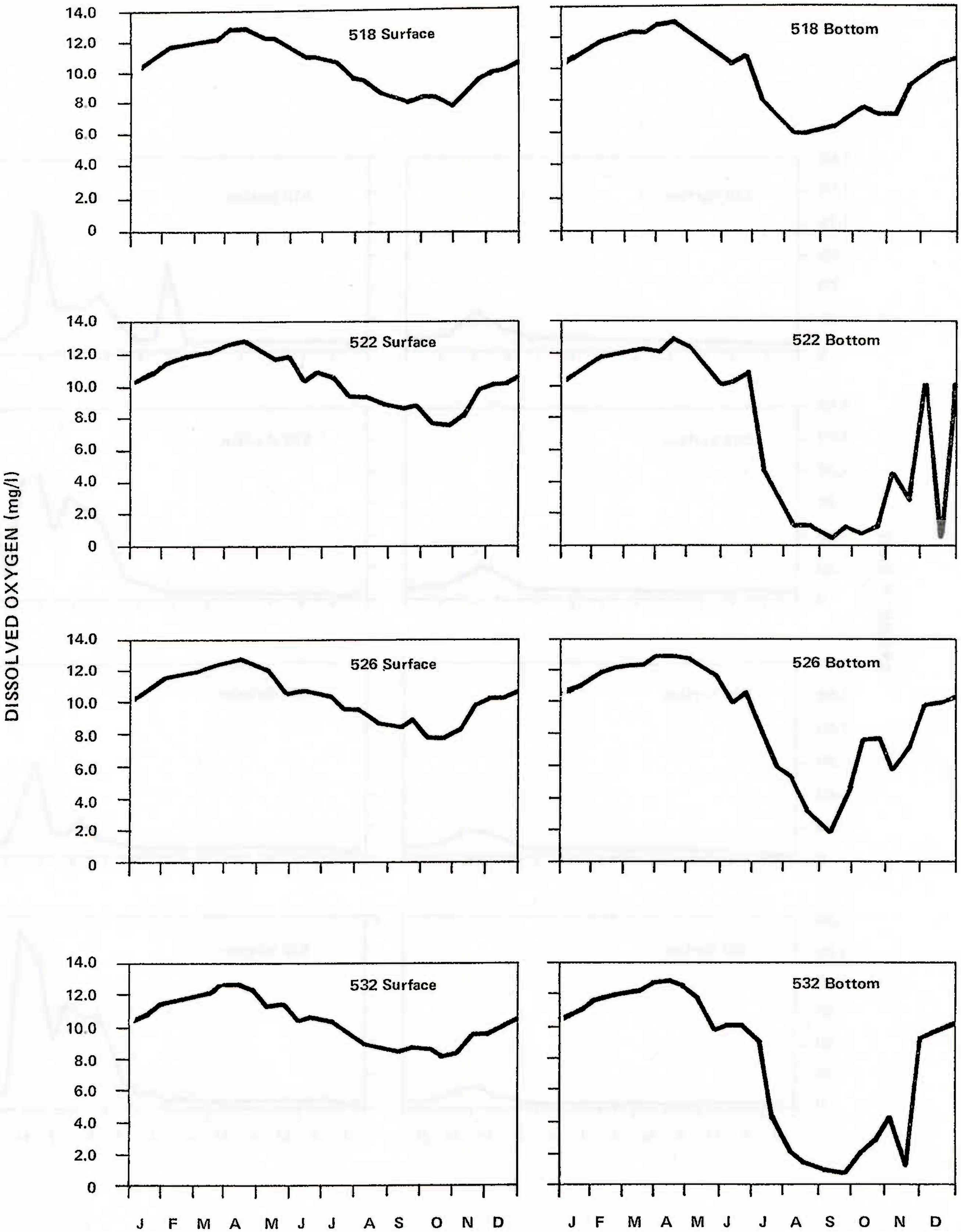


Fig. 4-3. Concentrations of dissolved oxygen at the surface and bottom of Lake Union, 1974.

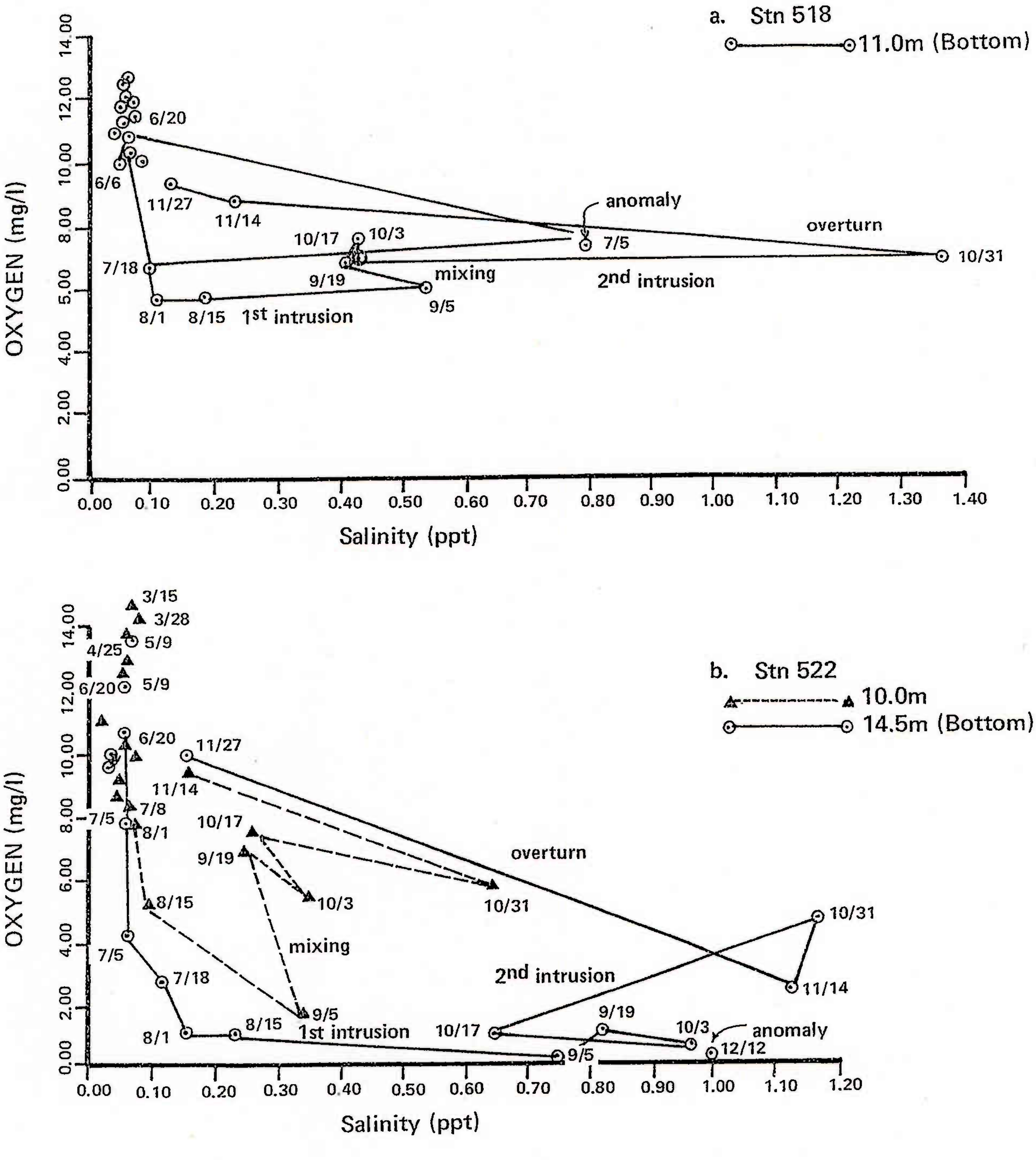
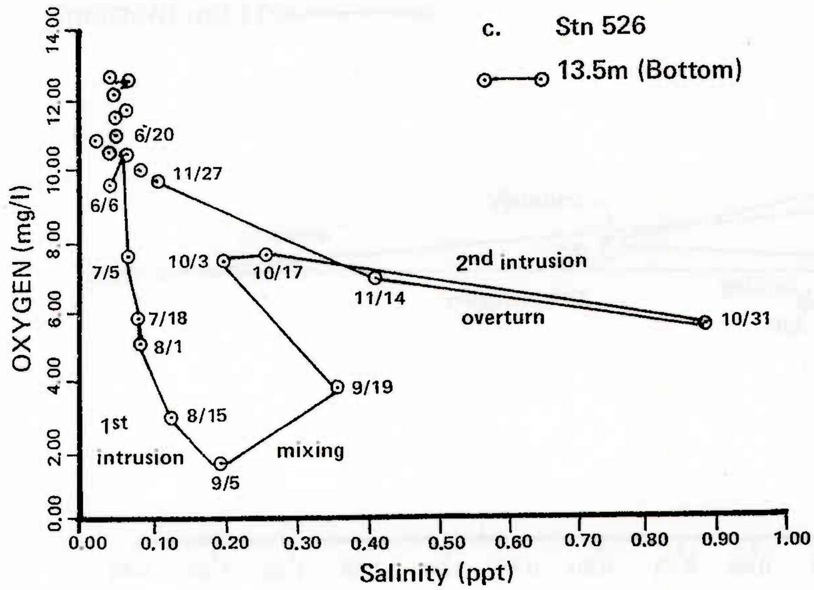


Fig. 4-4. Salinity vs dissolved oxygen in Lake Union, 1974.



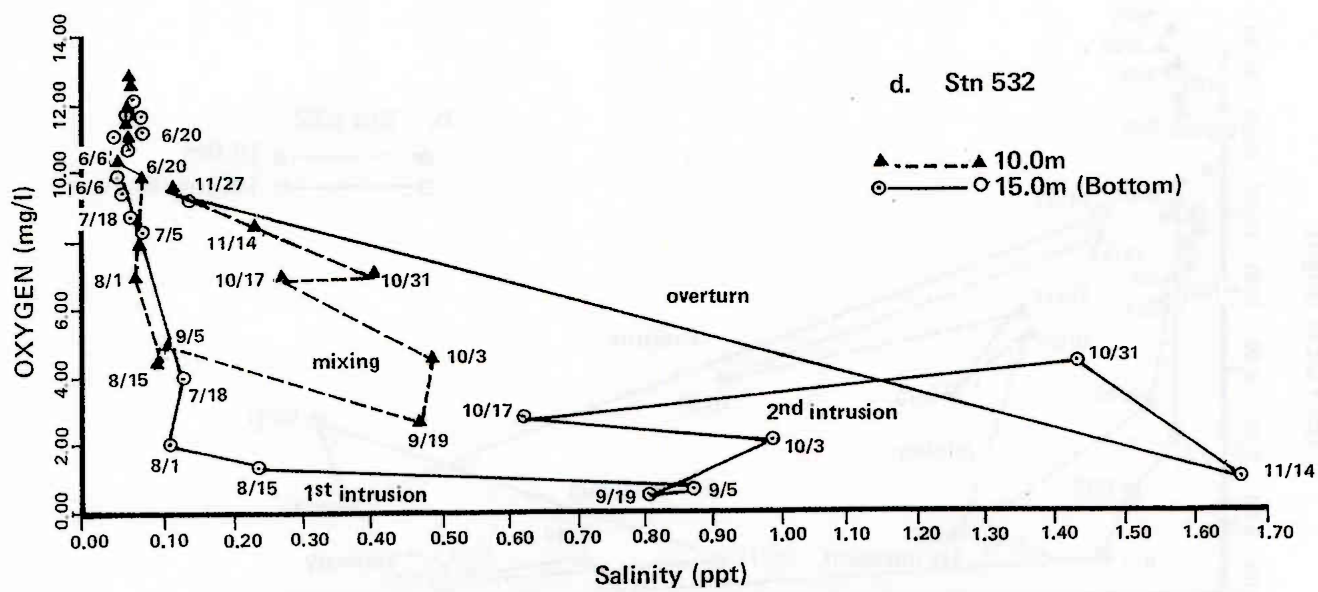


Fig. 4-4. (continued)

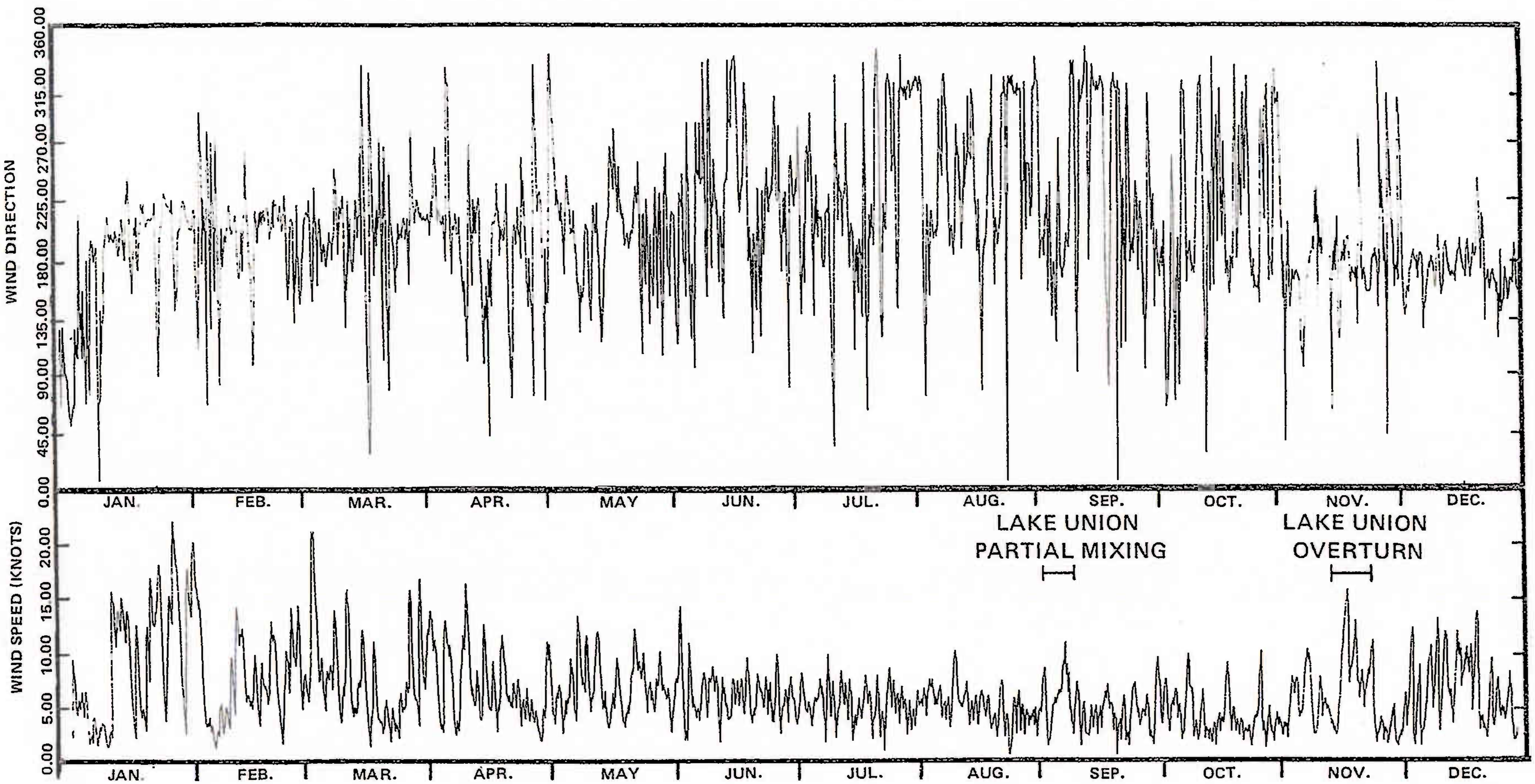


Fig. 4-5. Wind speed and direction as measured at the Puget Sound Air Pollution Control Association Stn. K-55 at E. Marginal Way S. in the Duwamish Valley Mean values for every third hour smoothed by six-point sliding-average technique.

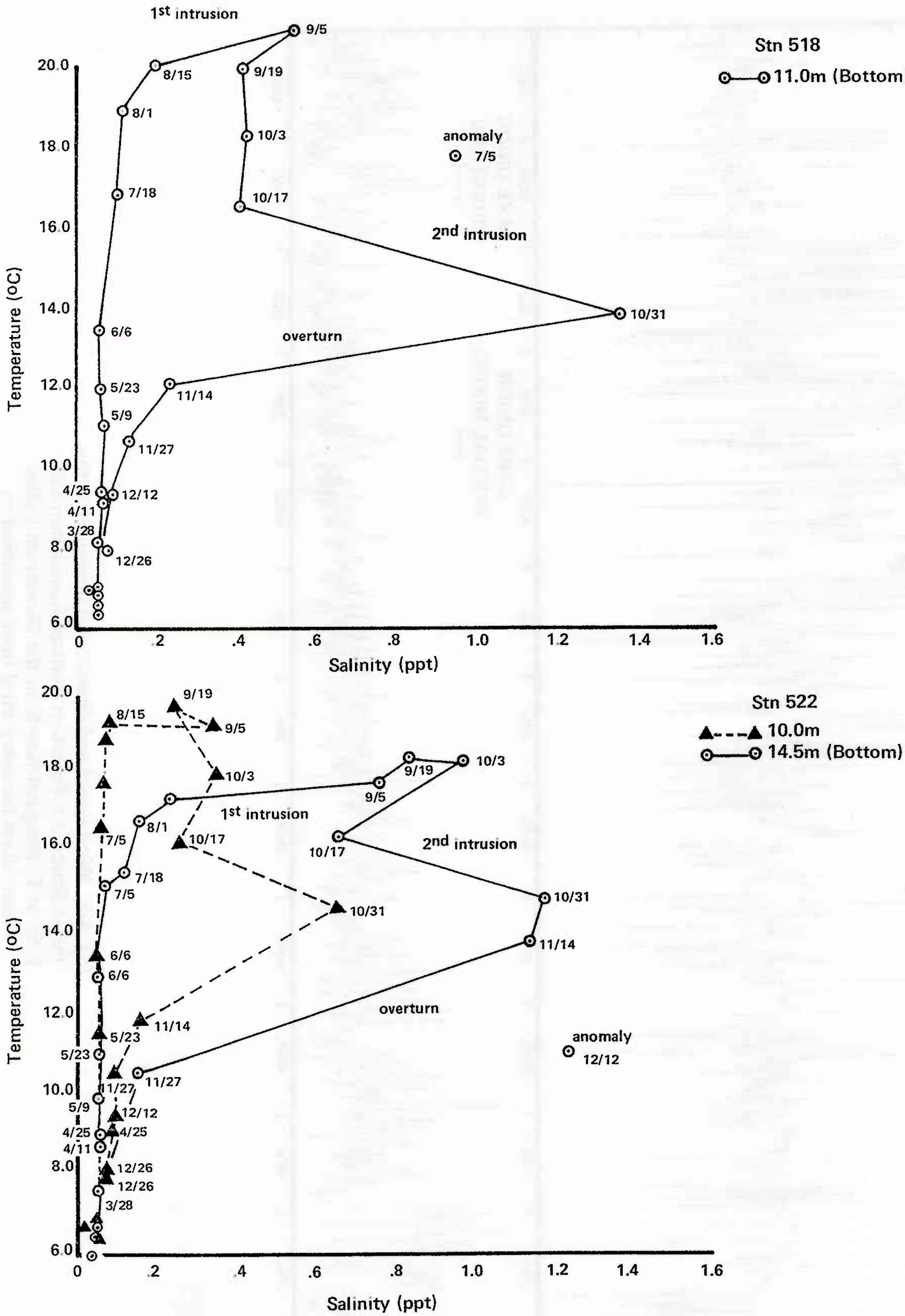


Fig. 4-6. Salinity vs temperature in Lake Union, 1974

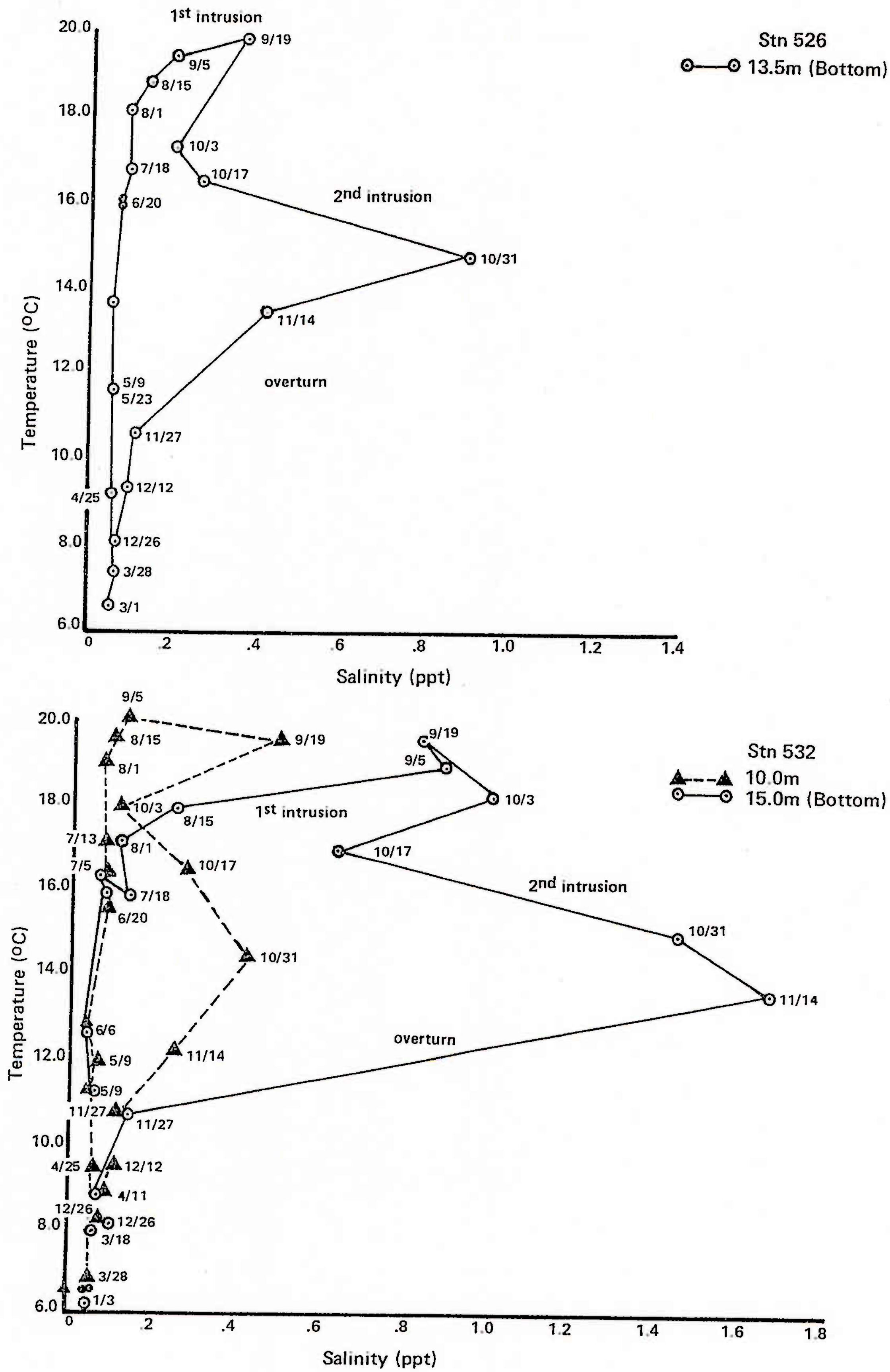


Fig. 4-6. (continued)

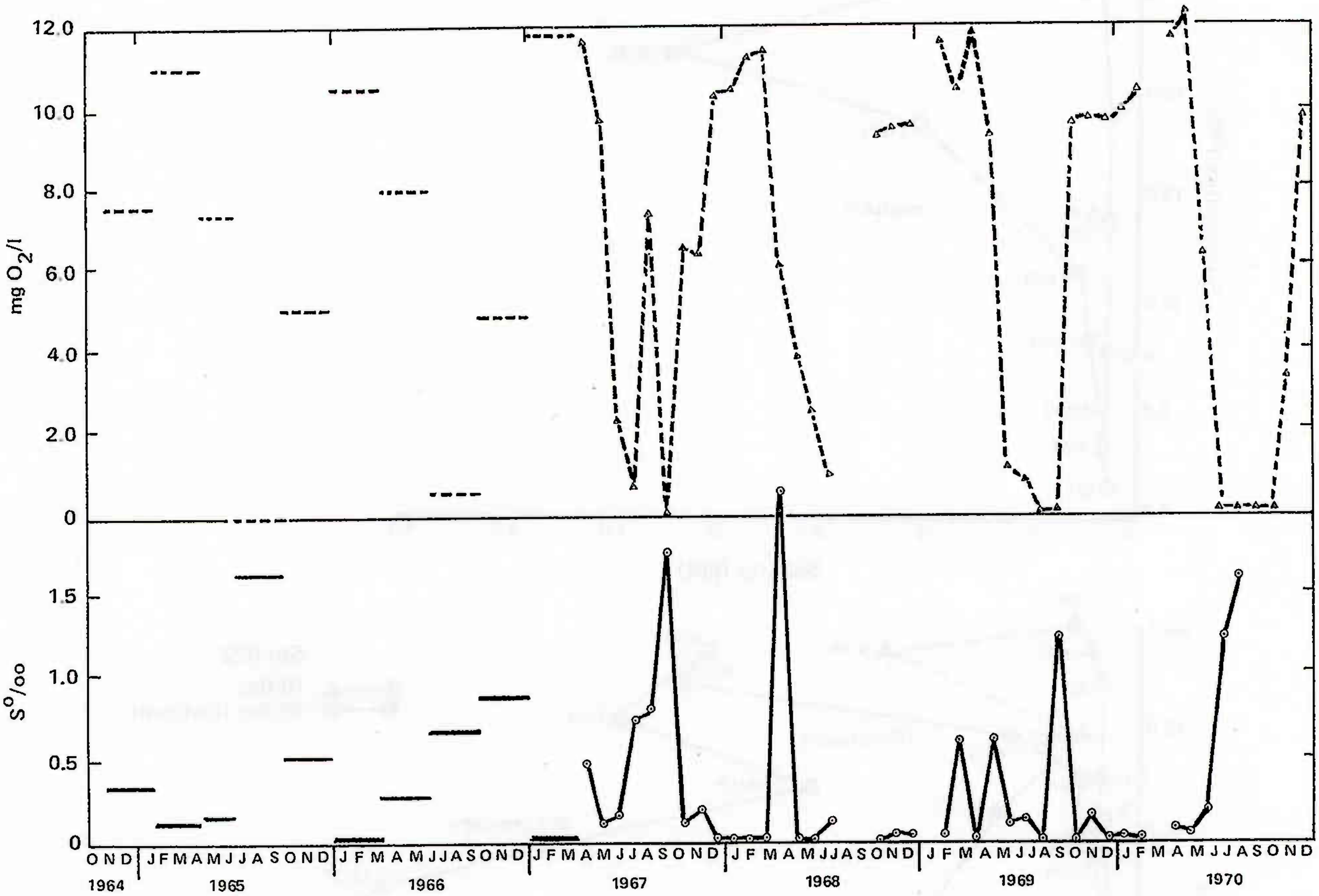


Fig. 4-7. Historical data on dissolved oxygen and salinity from Lake Union. All data were from Metro Station 532, at 14m depth.

Turbidity and Suspended Solids

In light of the foregoing discussion of seasonal circulation, the fluctuations observed in turbidity and concentration of suspended solids are not easily explained. Turbidity measurements in general were below 3.0 JTU for both surface and bottom at all stations (Fig. 4-8). The data show good station-to-station and surface-to-bottom correlation during periods of mixing and low chlorophyll concentrations but not during stratification and algal blooms, except at the bottom of the deep stations (522 and 532). High turbidities were measured in all samples on March 1, and low values were likewise detected everywhere on August 15 and again on October 31. There is no obvious explanation for these observations.

Surface values for suspended solids (Fig. 4-9) give evidence of good station-to-station correlation from May 9 to August 1. In general, concentrations of suspended solids fell during this time from 4.0-5.0 mg/l to near the annual minimum (0.3-0.5 mg/l) and returned to the annual maximum (.99-1.32 mg/l) by August 1. This period closely corresponded to the time of dieoff and depletion of the spring algal bloom, as indicated by chlorophyll a concentrations (Fig. 6-1). The exact nature of this relationship, be it more than coincidence, is unknown; indeed, the noted correspondence may have been indirect, and an independent causative factor may have been controlling the levels of both parameters.

As with the turbidities, the concentrations of suspended solids at the bottom of Stations 522 and 532 show similar trends throughout the year. However, in general there is no obvious correlation between the two parameters. Large peaks in suspended solids (up to 16.5 mg/l) were recorded at these depths on August 1. As previously mentioned, turbidities at that time were quite low. Since the arrival of the saltwater tongue took place at this time also, the measurement may well reflect the high particle densities characteristically associated with a saltwater-freshwater interface. If the average particle radius were relatively large, turbidity measurements of the intruding water might actually drop, as observed, owing to decreased attenuation of light and backscatter. It can be conjectured further that the second intrusion, which immediately followed a period of high stability and reduced fallout of organic particulates, presented a relatively "clean" interface. During this period, October 17-31, a sharp drop in turbidity occurred the bottom at all stations but no significant change in suspended solids.

The effects of high seasonal runoff were manifest in the high turbidity and/or suspended solids levels seen sporadically in January and December at all stations. During the same intervals high phosphate, chlorophyll, and iron concentrations appeared randomly throughout the water column.

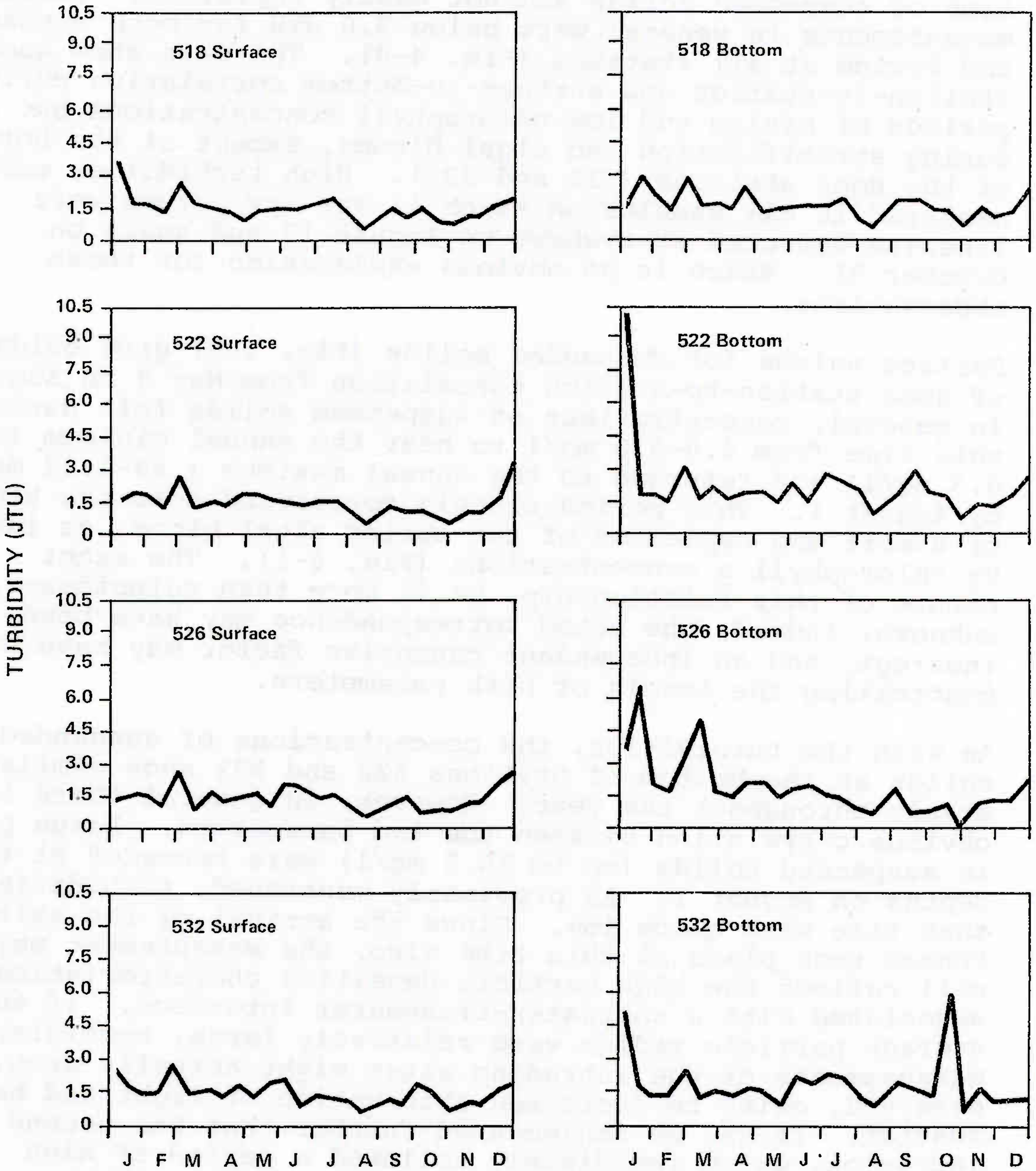


Fig. 4-8. Turbidities at the surface and bottom of Lake Union, 1974.

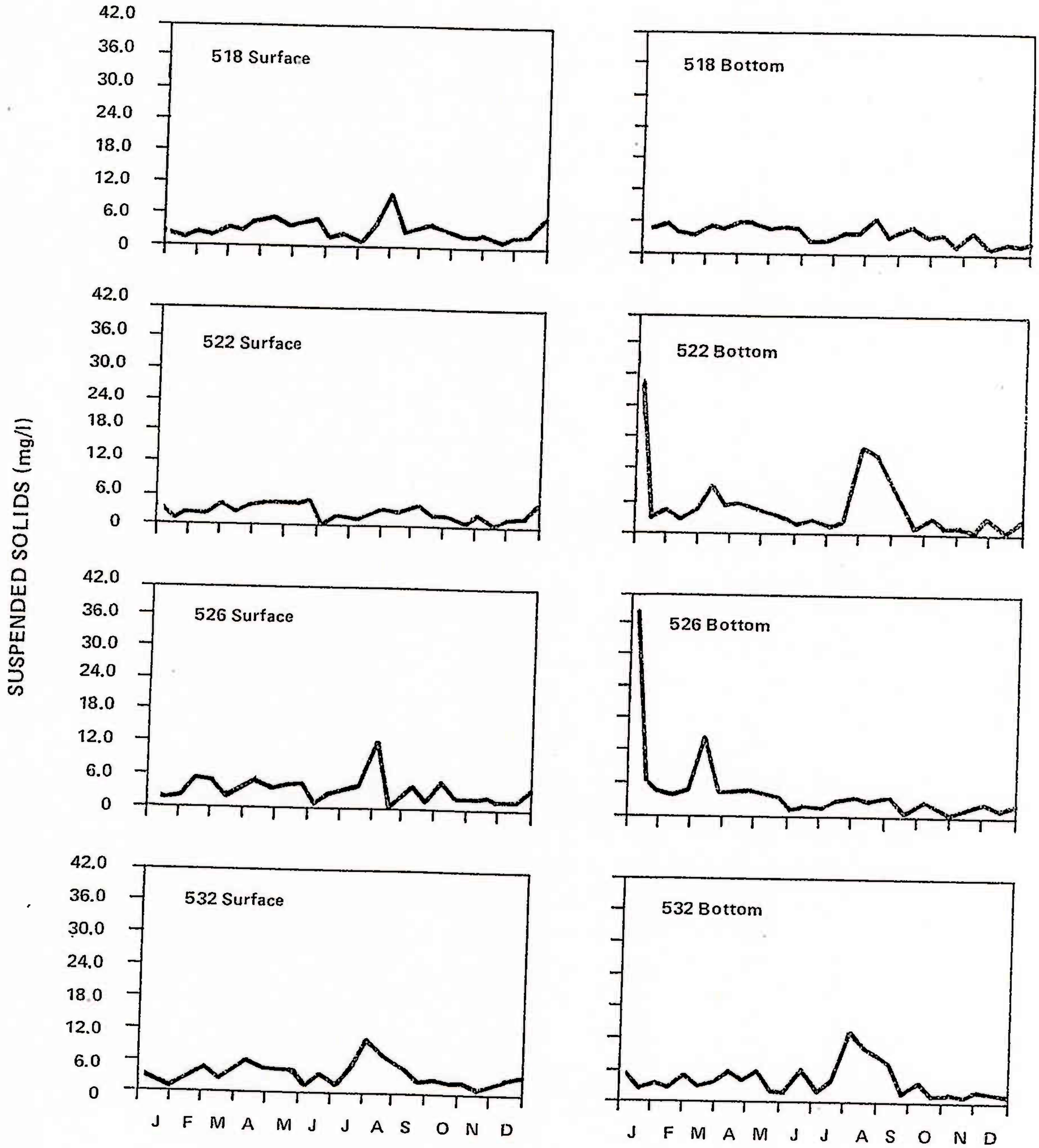


Fig. 4-9. Concentrations of suspended solids at the surface and bottom of Lake Union, 1974.

CHEMISTRY

Phosphate and Iron

The phosphate and iron cycles in Lake Union are inextricably linked and will therefore be discussed together. The seasonal variations of these two parameters at the four sampling stations are presented in Figs. 4-10 and 4-11. The data on orthophosphate presented in this report were taken from unfiltered samples. Further studies showed that a correction factor of .003 mg PO_4-P/l per JTU for turbidities within the range, 0-5.0 JTU, must be subtracted from the orthophosphate data. The corrected data for turbidities greater than 2.0 JTU are listed in Table A-1; uncorrected data appear in Fig. 4-10 and Appendix C. Generally, the dissolved orthophosphate levels were low. The average concentration at the surface for the year was .02 mg PO_4-P/l. However, during January-February, June-July, and October, concentrations were appreciably higher at the surface and bottom at all stations. The possible significance of these peaks, which preceded algal blooms, will be further discussed in Section 6.

At the bottom of Stations 522 and 532 the data indicate massive buildups of both orthophosphorus and iron between July and November. The phenomenon was brought about by both biological and chemical factors. The initial increase in phosphate on July 5 occurred as dissolved oxygen concentrations near the bottom had begun to decrease but were still above 4.0 mg O_2/l at all stations. The depletion of oxygen and increase in phosphate were due to the decomposition of organic matter from the largest algal bloom observed in 1974, which had just diminished to baseline cell levels. Contamination of samples may account for most of the high iron values obtained on April 25.

When the oxygen content fell below the inhibitory threshold value of 2 mg/l (Fillos and Molof, 1972), phosphorus bound in the sediments as a "mixed" ferric hydroxo-phosphate precipitate (Stumm and Morgan, 1970) was released, initially through bacterial action (Shapiro et al., 1967; Fillos and Molof, 1972), and subsequently through reduction of the iron to the more soluble ferrous form. With the advent of the November overturn, the process was reversed, and the precipitate was again incorporated into the sediments. For reasons unknown, on April 25 iron concentrations were high near the bottom and at the surface but not at 5 and 10 m. The samples may have been contaminated. The possible origin of the high phosphate concentrations near the bottom at Station 522 in mid-December has been discussed.

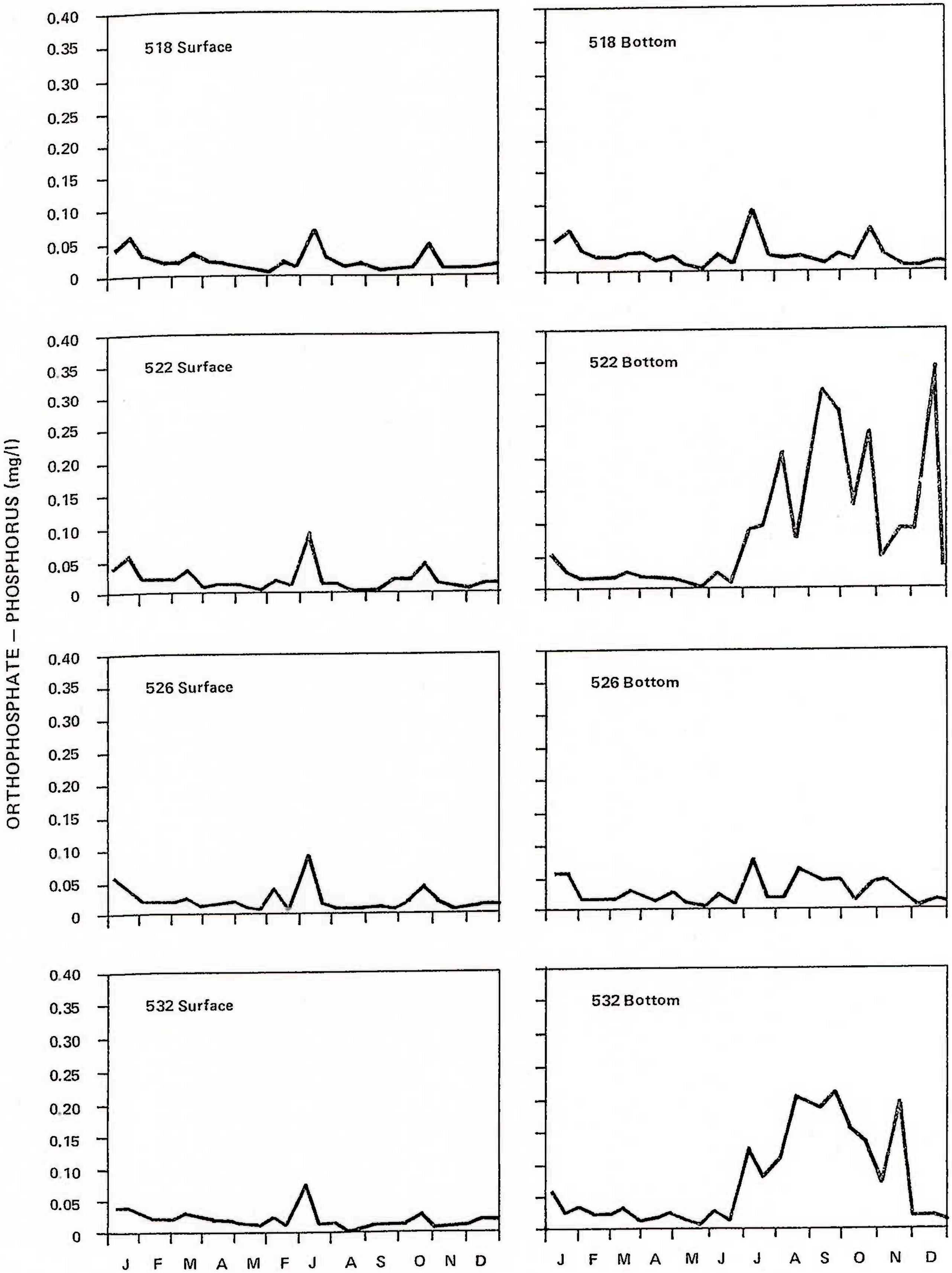


Fig. 4-10. Concentrations of orthophosphate at the surface and bottom of Lake Union, 1974.

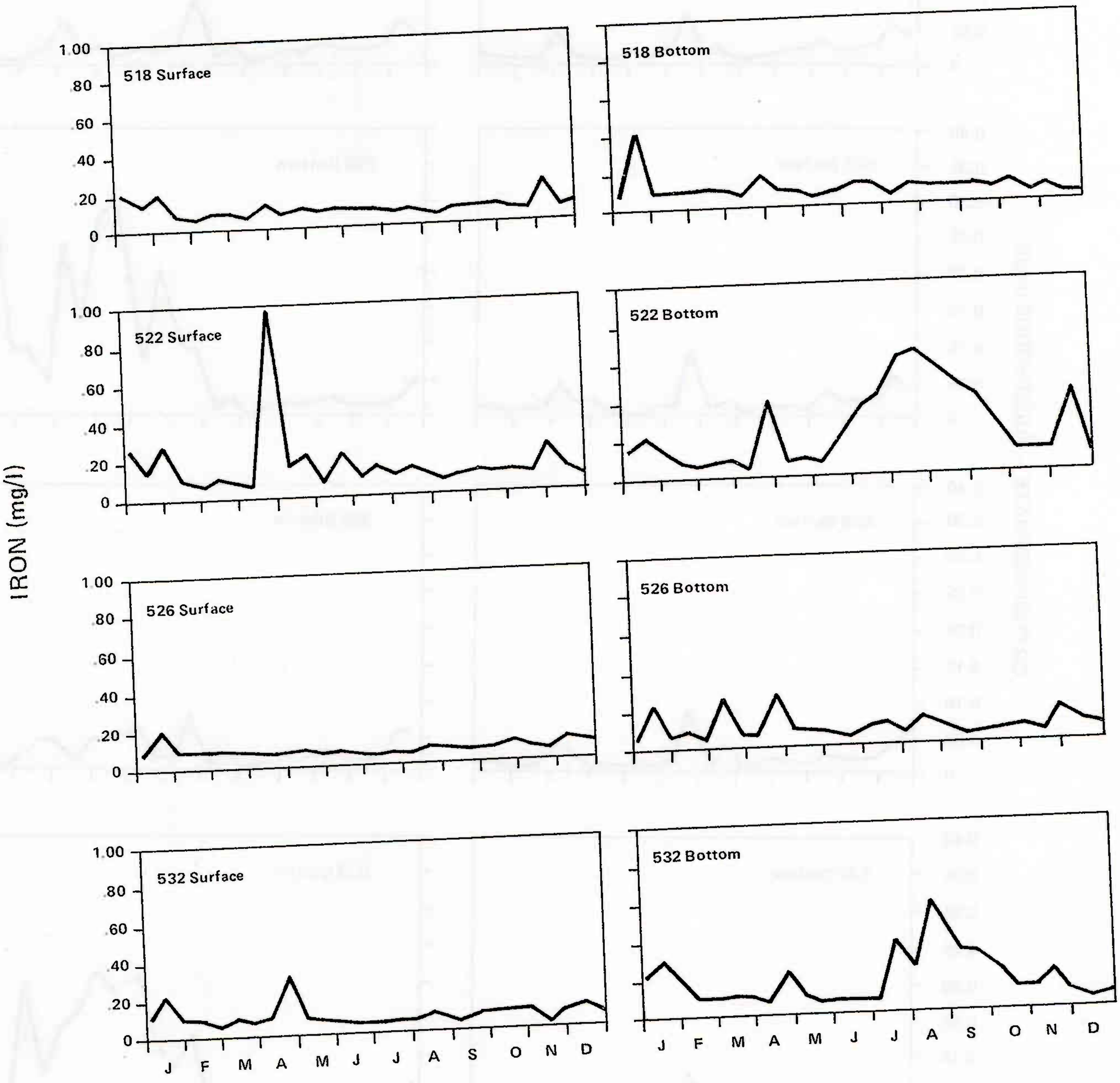


Fig. 4-11. Concentrations of iron at the surface and bottom of Lake Union, 1974.

Nitrate + Nitrite and Ammonia

The patterns of fluctuations in concentrations of nitrate + nitrite and ammonia are typical of an eutrophic lake with a seasonally stagnant hypolimnion. As shown by Fig. 4-12, the nitrate + nitrite levels reached their maxima in the spring, began to decline at the onset of the spring blooms, fell to their seasonal minima with the advent of hypolimnetic stagnation, and increased again following the fall overturn. This cycle was apparent at all stations at both the surface and bottom although mean values were somewhat higher at the bottom than at the surface during the summer months.

The annual ammonia cycle (Fig. 4-13) was approximately the inverse: concentrations were low in the spring, rose (as a function of depth and dissolved oxygen depletion) through the summer and fall, and diminished abruptly at the time of overturn.

The buildup of nitrogen in the spring was terminated by the appearance of algal blooms. The effects of the production are graphically evident in Fig. 4-12 and B-4.1. In mid-March, the concentration of NO_3 + NO_2 -N/l began to decrease at all levels in the water column. The rate of apparent utilization was much higher at depths < 5 m than deeper, so that the surface appears to be the stratum of maximum production. As is discussed in Section 6, the absence of large populations of productive cells below 5 m probably implies no production at depth, and decreases in nitrogen concentrations near the bottom during this time largely represented the effects of vertical mixing and near-surface utilization.

Thermal stratification first became apparent in mid-April and isolated the surface blooms from the sediment nutrient supply. As a consequence, algal production peaked (see Fig. 6-2) and began to diminish. The combination of algal utilization, density stratification, and anaerobic sedimentation then served to keep NO_3 + NO_2 concentrations very low during the summer and early fall. Mixing and overturn reversed these circumstances, and the cycle became complete with the winter buildup (Fig. 4-12).

Coincident with the midsummer occurrence of anoxic conditions in the hypolimnion, the residual nitrate + nitrite was gradually converted to ammonia by denitrifying bacteria. The reduction process was particularly evident near the bottom during the period August 1 - September 19 (see Fig. B-4.1).

Solubilization of organically bound nitrogen from settling plankton and detritus, and release of ammonia and soluble kjeldahl nitrogen from the sediments (Austin and Lee, 1973) also proceeded under these conditions. The net effect was

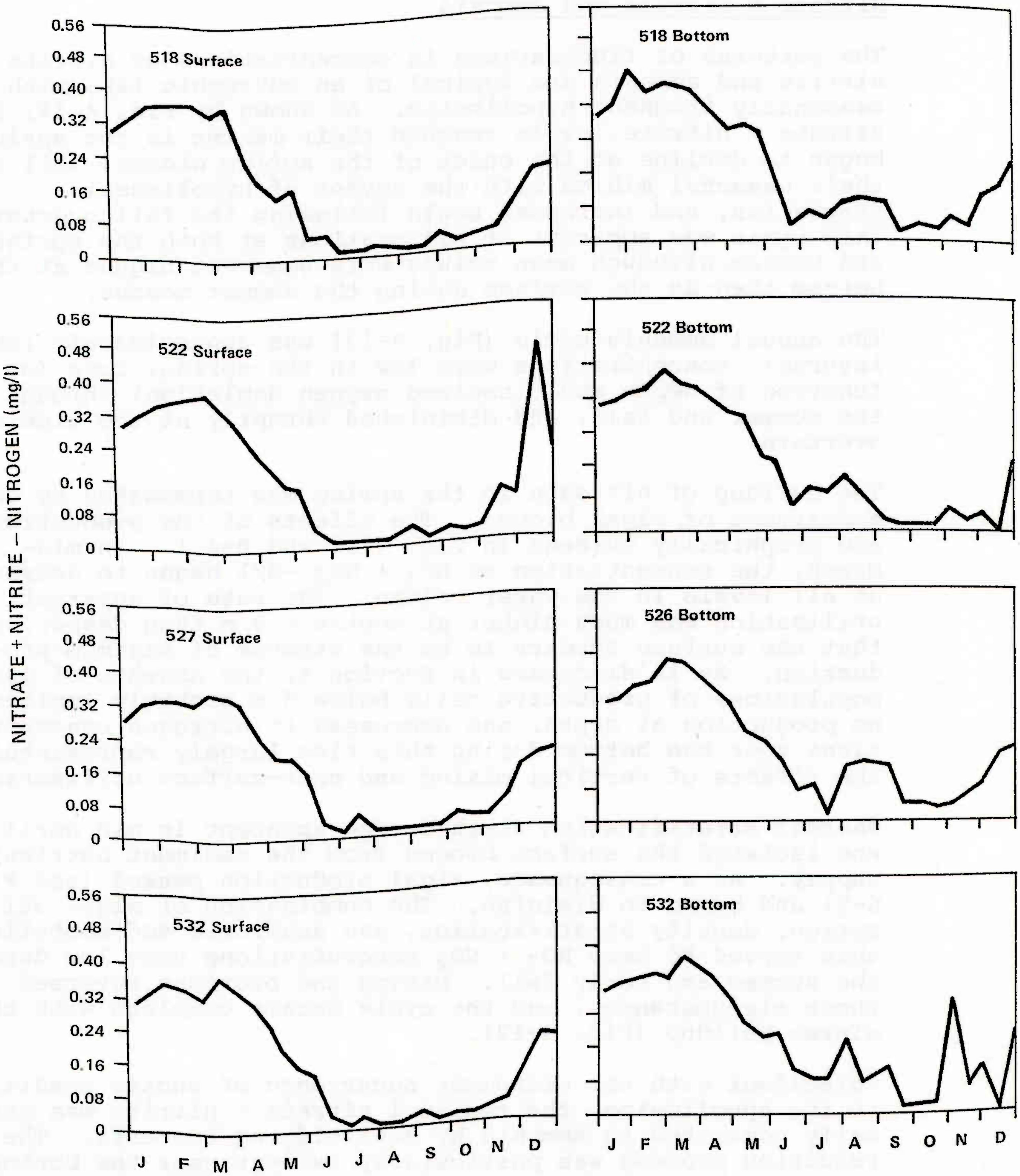


Fig. 4-12. Concentrations of nitrate + nitrite at the surface and bottom of Lake Union, 1974.

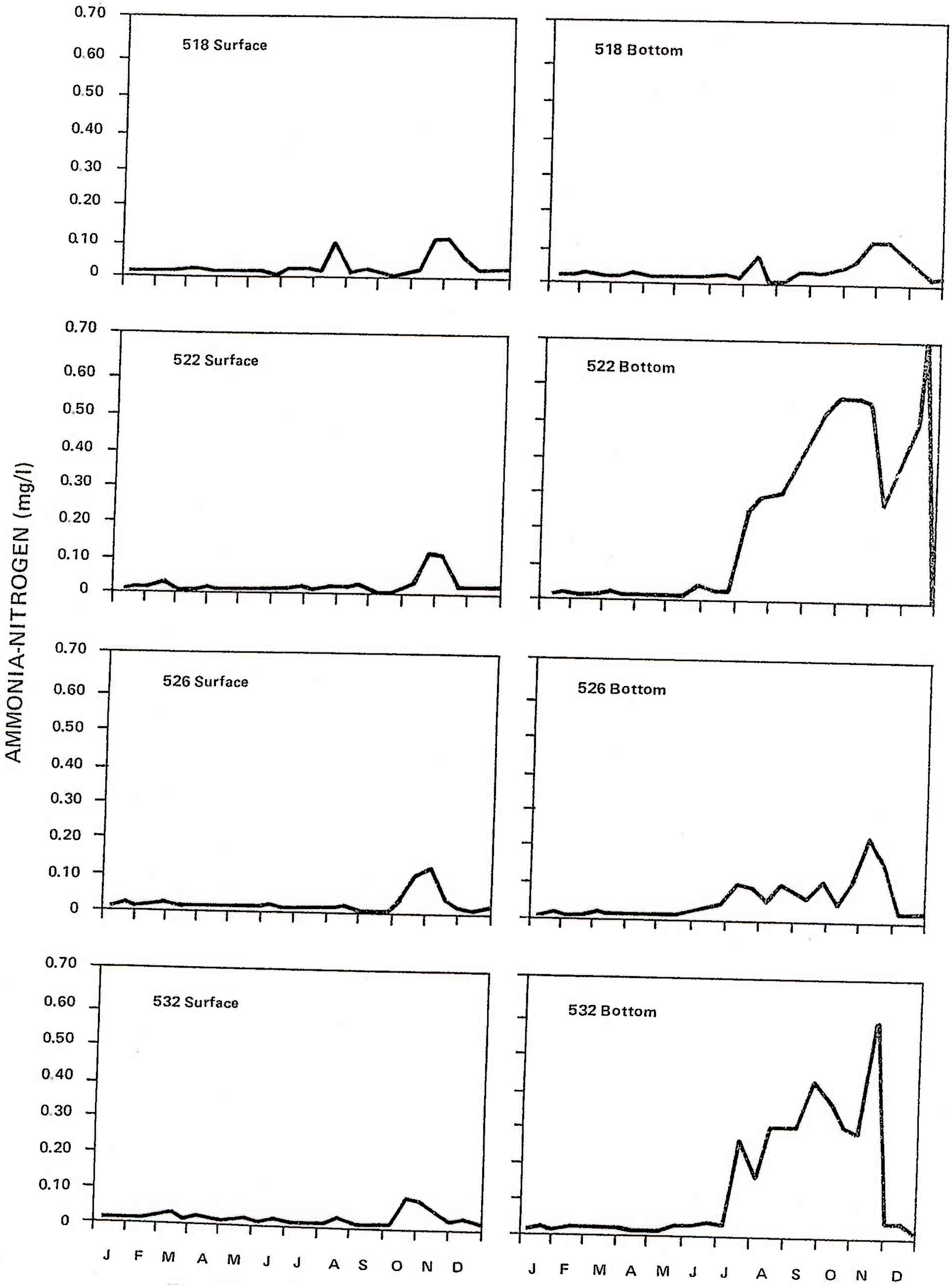


Fig. 4-13. Concentrations of ammonia at the surface and bottom of Lake Union, 1974.

the continued release and buildup of dissolved nitrogen compounds throughout the period of stratification (Fig. 4-13). During this time, small blooms of blue-green algae (Fig. 6-2) may have contributed significant amounts of nitrate and nitrite through nitrogen fixation. The possibility is further analyzed in the discussion on phytoplankton.

An increase was observed in surface concentrations of ammonia at all stations in mid-October concomitant with an increase in surface salinities. The profiles for stations 522 and 532 show that these conditions had prevailed between 5 and 10 m two weeks before; therefore the surface peaks may have been the results of wind-driven vertical mixing. When we consider the relatively high levels of oxygen above 10 m during this interval, the extended persistence of reduced nitrogen species is somewhat unexpected; the nitrification process is generally quite rapid in the presence of oxygen (Ruttner, 1952) but can be delayed in the absence of nitrifying bacteria.

Heavy Metals (Other Than Iron)

The concentrations of six other metals besides iron were monitored in the water column. The annual minimum, maximum, and mean concentrations of cadmium, chromium, copper, lead, nickel, and zinc are listed in Table 4-1. All of the cadmium, chromium, and nickel concentrations and most of the lead concentrations fell below the detection limits of the Atomic Absorption Spectrophotometer and are therefore represented in the table as less than (<) these levels. On September 12, 1974 the Perkin-Elmer Model 303 AAS was replaced by an Instrument Laboratory Model 453 AAS, which has a lower detection limit for lead. Thus, the annual mean lead values were considered nonrepresentative of a full year's data and were omitted. All detectable lead concentrations are listed in Appendix C.

Generally speaking, differences from station to station were insignificant. Mean zinc concentrations approximated the .019 mg/l value determined by Spyridakis and Barnes (1976) for the Lake Washington water column. Their value of 1.7 ug/l for copper, however, was an order of magnitude lower than that measured for Lake Union. Anomalously high copper concentrations were detected at all stations on January 3 and 17 and April 25; high values for both copper and lead were also evident at three stations on November 27. Similar trends for zinc indicate that a common controlling mechanism may be involved. It is of interest to note that high concentrations of all three of these metals have been found in combined sewer overflows (Tomlinson et al., 1976) at outfall 132 (see Fig. B-4.2). Although no record of combined discharge volumes exists for non-Metro outfalls in Lake Union, overflows must have been substantial in mid-January and

Table 4-1. Concentrations of Heavy Metals in the Water Column of Lake Union, 1974

Station	Depth (m)	CADMIUM Min. mg/l	CADMIUM Max. mg/l	CADMIUM Mean mg/l	CHROMIUM Min. mg/l	CHROMIUM Max. mg/l	CHROMIUM Mean mg/l	COPPER Min. mg/l	COPPER Max. mg/l	COPPER Mean[1] mg/l	LEAD Min. mg/l	LEAD Max. mg/l	LEAD Mean[2] mg/l	NICKEL Min. mg/l	NICKEL Max. mg/l	NICKEL Mean[1] mg/l	ZINC Min. mg/l	ZINC Max. mg/l	ZINC Mean[1] mg/l
518	1.0	<0.004	<0.004	<0.004	<0.01	<0.01	<0.01	<0.01	0.09	0.01-0.02	<0.05	<0.10	—	<0.05	<0.05	<0.05	<0.005	0.027	0.012-0.013
	11.0	<0.004	<0.004	<0.004	<0.01	<0.01	<0.01	<0.01	0.09	0.01-0.02	<0.05	<0.10	—	<0.05	<0.05	<0.05	<0.005	0.067	0.015-0.016
522	1.0	<0.004	<0.004	<0.004	<0.01	<0.01	<0.01	<0.01	0.41	0.03	<0.05	0.10	—	<0.05	<0.05	<0.05	<0.005	0.122	0.016-0.017
	5.0	<0.004	<0.004	<0.004	<0.01	<0.01	<0.01	<0.01	0.10	0.01-0.02	<0.05	<0.10	—	<0.05	<0.05	<0.05	<0.005	0.029	0.010-0.011
	10.0	<0.004	<0.004	<0.004	<0.01	<0.01	<0.01	<0.01	0.10	0.01-0.02	<0.05	<0.10	—	<0.05	<0.05	<0.05	<0.005	0.032	0.011
	14.5	<0.004	<0.004	<0.004	<0.01	<0.01	<0.01	<0.01	0.16	0.01-0.02	<0.05	<0.10	—	<0.05	<0.05	<0.05	<0.005	0.028	0.014
526	1.0	<0.004	<0.004	<0.004	<0.01	<0.01	<0.01	<0.01	0.08	0.01-0.02	<0.05	<0.10	—	<0.05	<0.05	<0.05	<0.005	0.026	0.010
	13.5	<0.004	<0.004	<0.004	<0.01	<0.01	<0.01	<0.01	0.04	0.00-0.01	<0.05	<0.10	—	<0.05	<0.05	<0.05	<0.005	0.020	0.010
532	1.0	<0.004	<0.004	<0.004	<0.01	<0.01	<0.01	<0.01	0.16	0.02	<0.05	<0.10	—	<0.05	<0.05	<0.05	<0.005	0.027	0.011-0.012
	5.0	<0.004	<0.004	<0.004	<0.01	<0.01	<0.01	<0.01	0.22	0.02	<0.05	0.10	—	<0.05	<0.05	<0.05	<0.005	0.035	0.099-0.011
	10.0	<0.004	<0.004	<0.004	<0.01	<0.01	<0.01	<0.01	0.19	0.01-0.02	<0.05	<0.10	—	<0.05	<0.05	<0.05	<0.005	0.028	0.009-0.010
	15.0	<0.004	<0.004	<0.004	<0.01	<0.01	<0.01	<0.01	0.12	0.01-0.02	<0.05	<0.10	—	<0.05	<0.05	<0.05	<0.005	0.026	0.010-0.012

(1) The range, N_1-N_2, was calculated as follows: N_1 represents the assumption that all values below the detection limit = 0; N_2 represents the assumption that these values = detection limit.

(2) The min. and max. values are indefinite due to the use of two different atomic absorption spectrophotometers (with different detection limits) during the study. The mean values were omitted as nonrepresentative of a full year's data.

toward the end of November because of the unusually heavy rains (Fig. B-1.4). The high metals concentrations recorded for April do not similarly correlate with rainfall but there is no obvious explanation aside from sample contamination. Overall, however, the few high data points have little bearing on the interpretation of a characteristic annual cycle.

The ultimate concern leading to environmental measurements of heavy metals is their potential toxicity to the biota. Perhaps the most comprehensive extant guidelines on evaluation of potential harm in metal concentrations are given in the U. S. Environmental Protection Agency report "Water Quality Criteria 1972" (National Academy of Sciences-National Academy of Engineering Committee on Water Quality Criteria, 1972).

The report represents the compilation of a vast amount of scientific and technical information and is considered a definitive summary of environmental toxicology. Accordingly, a selection of recommended maximum concentrations from this reference (refer to Table 4-2 for a summary) has been used for an evaluation of the conditions in Lake Union found in this study.

A comparison of the values in Table 4-1 with those in Table 4-2 immediately results in one conclusion: persistent concentrations of all the metals studied (in the water column) are probably within recommended environmental limits. However it should be noted that the specified levels for lead and nickel are below the detection limits of Metro instrumentation. The same is true for the maximum limits for cadmium and copper advised for invertebrate exposure.

Particularly with cadmium and copper, the findings of the present study do not provide adequate assurance of safety. On the basis of the estimated safe-to-lethal concentration ratios, true concentrations only slightly below detection limits could be toxic to the invertebrate biota. It should be noted that one of the most sensitive invertebrate indicator organisms used in such evaluations is the freshwater cladoceran Daphnia magna; other members of the same genus are among the most predominant zooplankters found in Lake Union. Sporadic high concentrations of copper, lead, and zinc should also be watched carefully lest they surreptitiously become prevalent.

One last disconcerting note concerns historical trends. With the exception of nickel and chromium, the concentrations in sediments of all of these metals have increased substantially in the last 80 years (refer to Section B-6).

Table 4-2. Recommendations and Guidelines on Maximum Metal Concentrations in Natural Waters (1)

Metal	Max. Conc. for Invertebrate Protection	Max. Conc. for Fish Protection	Est. Safe: Lethal Conc. Ratio
Cd	.0004 mg/l (2)	.004 mg/l	1:10
Cr (3)	.05 mg/l	.05 mg/l	1:25 - 1:250 (various fish) 1:7 (*Daphnia magna*)
Cu (4)	.006 mg/l	.01-.02 mg/l	1:5 - 1:10
Pb	.03 mg/l	.03 mg/l (5)	1:50
Ni (4)	.02-.03 mg/l	.02-.03 mg/l	1:50
Zn (4)	.07 mg/l	.01-.07 mg/l (6)	1:200

(1) From "Water Quality Criteria 1972." EPA Ecol. Res. Series. EPA-R3-73-033. March 1973.

(2) Values for waters having a total hardness ≤ 100 mg/l. Also maximum concentration recommended for salmon eggs and larvae.

(3) Danger levels are considered comparable for both valence states.

(4) Not formal recommendations, rather guidelines based on compiled research.

(5) Concentrations two to three times higher have been shown to have detrimental effects on various freshwater fishes.

(6) Estimated from fecundity tests on fathead minnow in hard water.

The trend implies a concurrent increase in concentrations in the water column. Until our knowledge assures us that the tendency is reversing and/or that these metals are present in nontoxic forms (and indeed some may be), diligent monitoring will be essential to safeguard the lake biota.

Coliforms

The counts of total and fecal coliforms at the surface are summarized in Fig. 4-14. In general the trends in counts of total coliforms were typical of a natural, freshwater body; i.e., counts are higher during the months of high runoff (January, February, March, November, and December) than during the drier portion of the year. In the Seattle area, sewer overflows contribute to this phenomenon for both total and fecal coliforms. Coliform levels at all four stations exceeded the limits currently specified by the Washington State Department of Ecology for Lake Class waters; i.e., "total coliform organisms shall not exceed median values of 240, with less than 20% of samples exceeding 1000 when associated with any fecal source."

Overall, counts of total coliforms were lower at Station 532 than at the other three stations. This observation is in agreement with the 6-year (1970-1975) means represented in Fig. B-7.1 and is thought to reflect the effects of the prevailing seaward circulation on sewer overflows into Lake Union. It is also interesting to note the (presently unexplainable) regular periodicity of fluctuations in counts of total coliforms at Stations 518 and 522, in which a high-low-high cycle occurred every 5 to 6 weeks during most of the year.

The distribution of coliforms over the water column at Station 522 was monitored by sampling at four depths (0 m, 5.0 m, 10.0 m and 14.5 m) in an attempt to correlate any high counts with the seasonal circulation patterns. With few exceptions the data on fecal coliforms were uniformly low and nondescript. The only significant exceptions were the values recorded for January 17 at all depths, (counts exceeding 400/100 ml) and the slightly higher than usual counts (100 counts/100 ml) found at most depths on January 31 and March 1, 15, and 28.

Although it was hoped that a prescheduled sampling run might occasionally coincide with or closely follow an overflow of the nearby (150 m due south) Galer Street outfall, three days (April 22-25) was the minimum time separating these two events. For this reason, the effects of the seven 1974 overflows (Table 4-3) are not evident in the coliform data from Station 522.

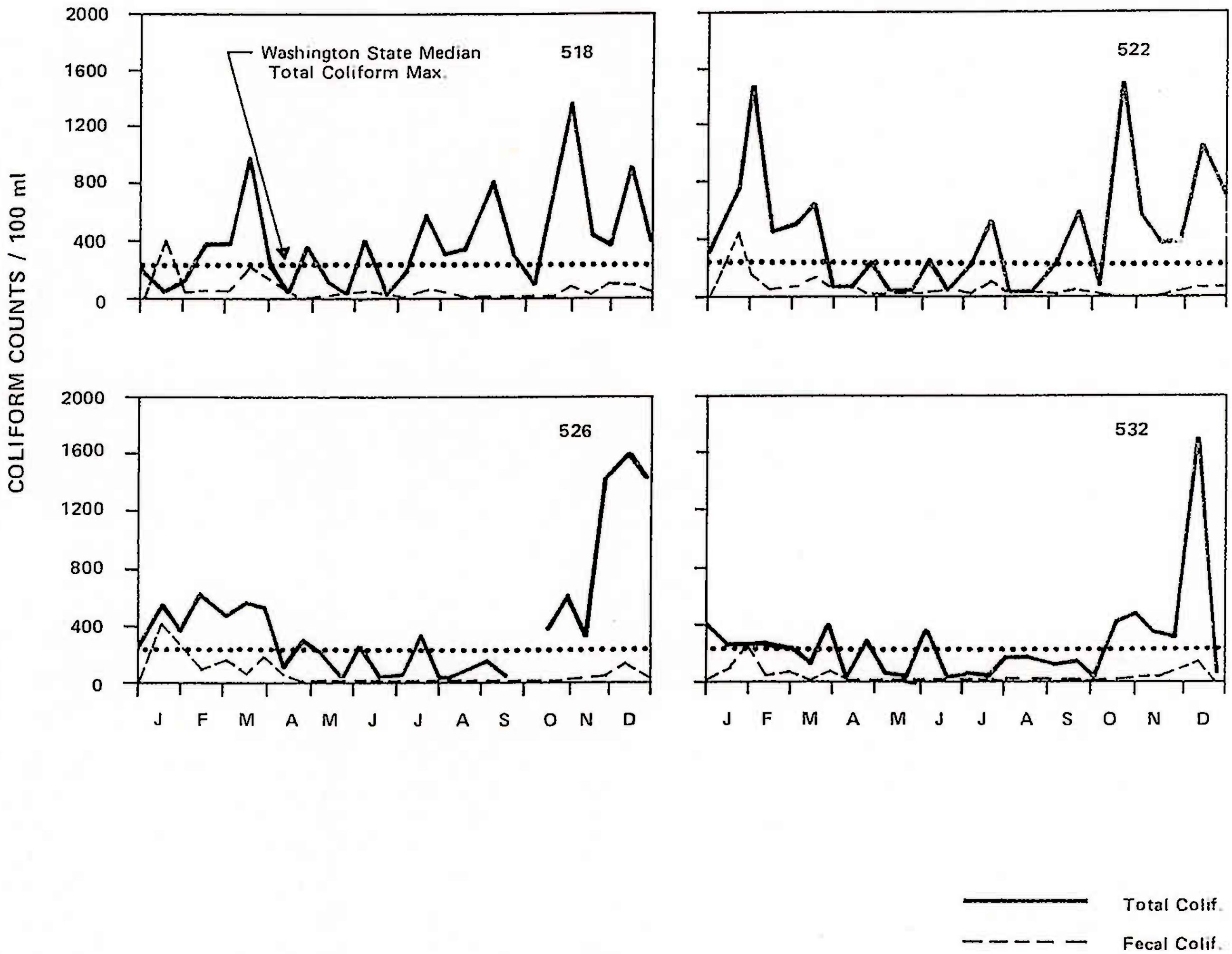


Fig. 4-14. Total and fecal coliform counts at the surface of Lake Union, 1974.

Table 4-3. Summary of 1974 Sewer Discharges at Metro's Galer Street Overflow

Date	Volume Lost (Millions of Gallons)
Apr. 22	.41
July 9	.07
Oct. 20	1.56
Nov. 17	1.77
Nov. 18	.26
Dec. 21	.45
Dec. 26	1.51
Total	6.03

On the other hand, the counts of total coliforms prominently reflect certain aspects of the circulation in Lake Union. A summary of the depth profiles of total coliforms at Station 522 is given in Fig. 4-15. During periods of weak or non-existent stratification (Jan.-Mar., Sept.-mid-Oct., mid-Nov.-Dec.), relatively high counts of total coliforms were found throughout the water column. With one exception, the levels were consistently low during the balance of the year. After four full months of low counts of total coliforms from surface to bottom, values at the bottom increased abruptly on Aug. 15 and again on Sept. 5 (Fig. 4-15).

This change coincided with the arrival of the first saltwater intrusion from the Fremont Channel. Bottom samples taken at Stations 518 and 532 on Sept. 5 also had relatively high (2130 and 1570/100 mls) counts of total coliforms. The corresponding counts of fecal coliforms at all three stations were very low.

If we assume that the observed high counts for total coliforms were closely associated with the saltwater intrusion, the question arises as to the ultimate source. Counts of total coliforms from Metro Station 224 at the mouth of the ship canal (Fig. D-1) included median surface values of 190, 1000 and 180 counts/100 mls for July, August, and September of 1974, respectively (the corresponding counts of fecal coliforms were 44, 67 and 42/100 ml). If we consider these values to be representative of the saltwater entering the Hiram Chittenden Locks, we can rule out this input as the major source of the high coliform counts associated with saltwater intrusion into Lake Union. In light of the 38:1 dilution of the saline bottom water of the lake, considerable bacterial growth and/or additional input would have to occur during the period of flow through Salmon Bay and the Fremont Channel to provide the relatively high counts observed at Stations 518, 522, and 532. Additional bacteria from unknown sources would appear to be the more logical explanation. Possible sources might include particulate fallout from near-surface waters, combined wastewater from sewer outfalls, and resuspension of sediments through bottom scouring.

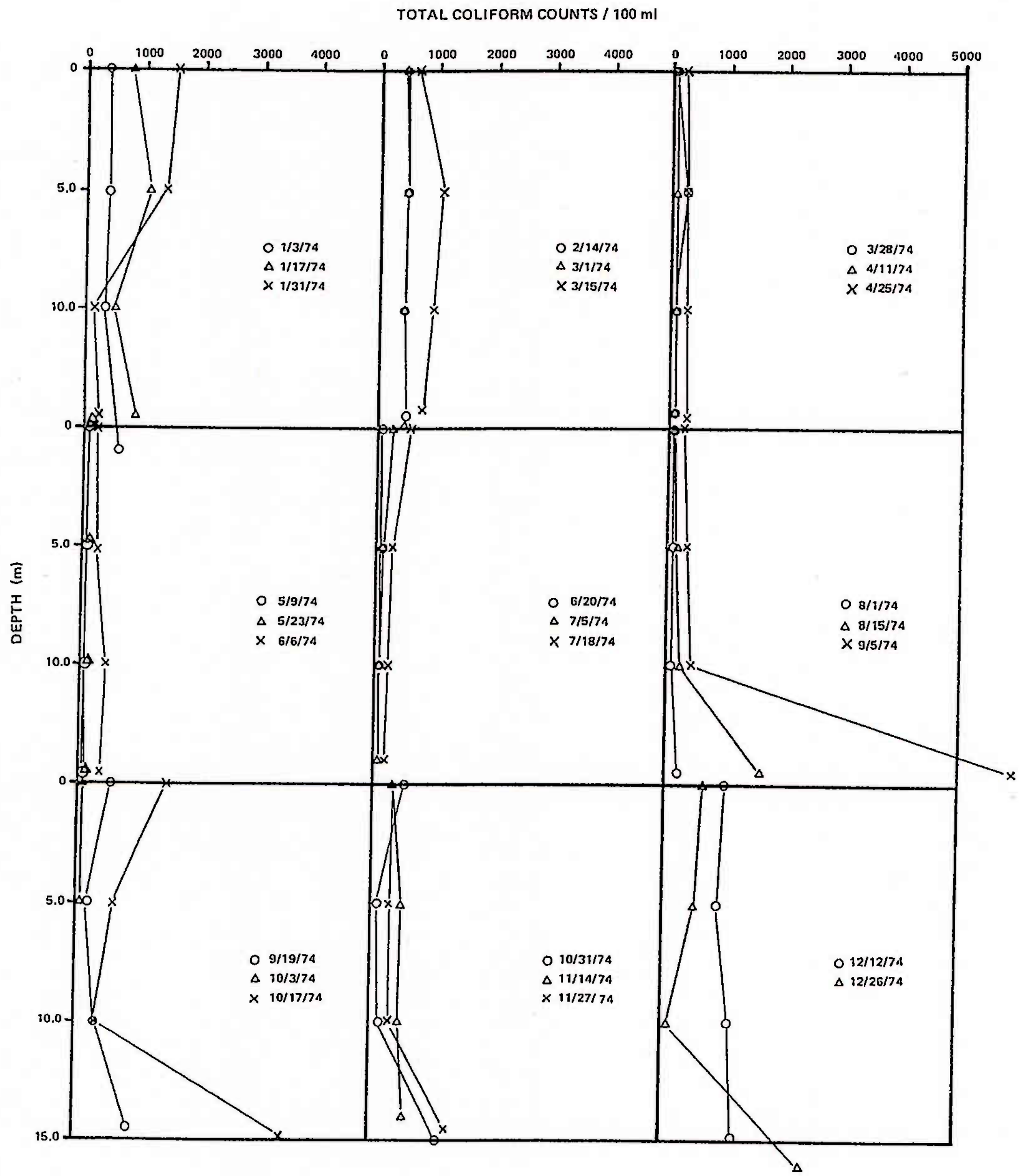


Fig. 4-15. Depth profiles of total coliforms at Lake Union Station 522, 1974.

Metro has been monitoring the abundance of coliforms at the surface in the Lake Washington Ship Canal since 1964. To add some degree of both temporal and spatial perspective to the Lake Union data, we have summarized trends in median counts of total coliforms in Fig. 4-16 for Stations 516, 518, 532, and 542. Stations 518 and 532 correspond to the Lake Union inlet/outlet sampling sites in the present study; the locations of Stations 516 and 542 are denoted by Fig. B-7.1. The trends at Station 516 are representative of those in Salmon Bay. Those at Station 542 are characteristic of Lake Washington.

Some sanitary engineering events that have significantly influenced coliform levels in the ship canal are also noted in Fig. 4-16. The circumstance having the greatest impact was probably the reduction and final elimination of routine sewage discharge to Lake Washington (refer to discussion in Sections B-7 and B-8). During 1967 input was reduced from 10.2 to 0.2 mgd, and a drop of at least one order of magnitude in median counts of total coliforms was observed subsequently at all "downstream" stations. Since the effluents of wastewater treatment plants discharging into Lake Washington were being chlorinated, so that most of their potential effect on coliform levels was eliminated, overloading by winter rains was (and still is) probably the main source of observed high levels.

Part of the decrease mentioned before (shown in Fig. 4-16), however, may be ascribed to a concurrent change in analytical methodology. On September 9, 1967 Metro began estimating coliform levels by the membrane filter technique; by this method slightly lower counts are obtained than by the previously used multiple-tube fermentation procedure (Cecil Whitmore, personal communication).

Two other projects also had a marked influence on counts of total coliforms. A bypass of part of the North Trunk Sewer (for repair purposes) between October 19 and December 1, 1965 caused millions of gallons of raw sewage to be dumped into Salmon Bay. Counts of total coliforms at Station 516 reached 200,000 during this interval. Owing to the prevailing seaward flow during the late fall and winter months, no influence of this contamination was seen at the lake stations. Similarly, when the Montlake siphon was cleaned in December, 1969, high coliform levels were detected only at stations seaward of _that_ point (Stations 516, 518 and 532 in Fig. 4-16).

The high values evident at Stations 516 and 518 in September and December, 1968 are probably the effects of sewer overflows caused by unusually heavy precipitation. There is only a hint of this influence at Station 532, an observation very much in keeping with the relatively low coliform levels noted earlier for this station, as compared with Stations 518, 522 and 526 (Fig. 4-14).

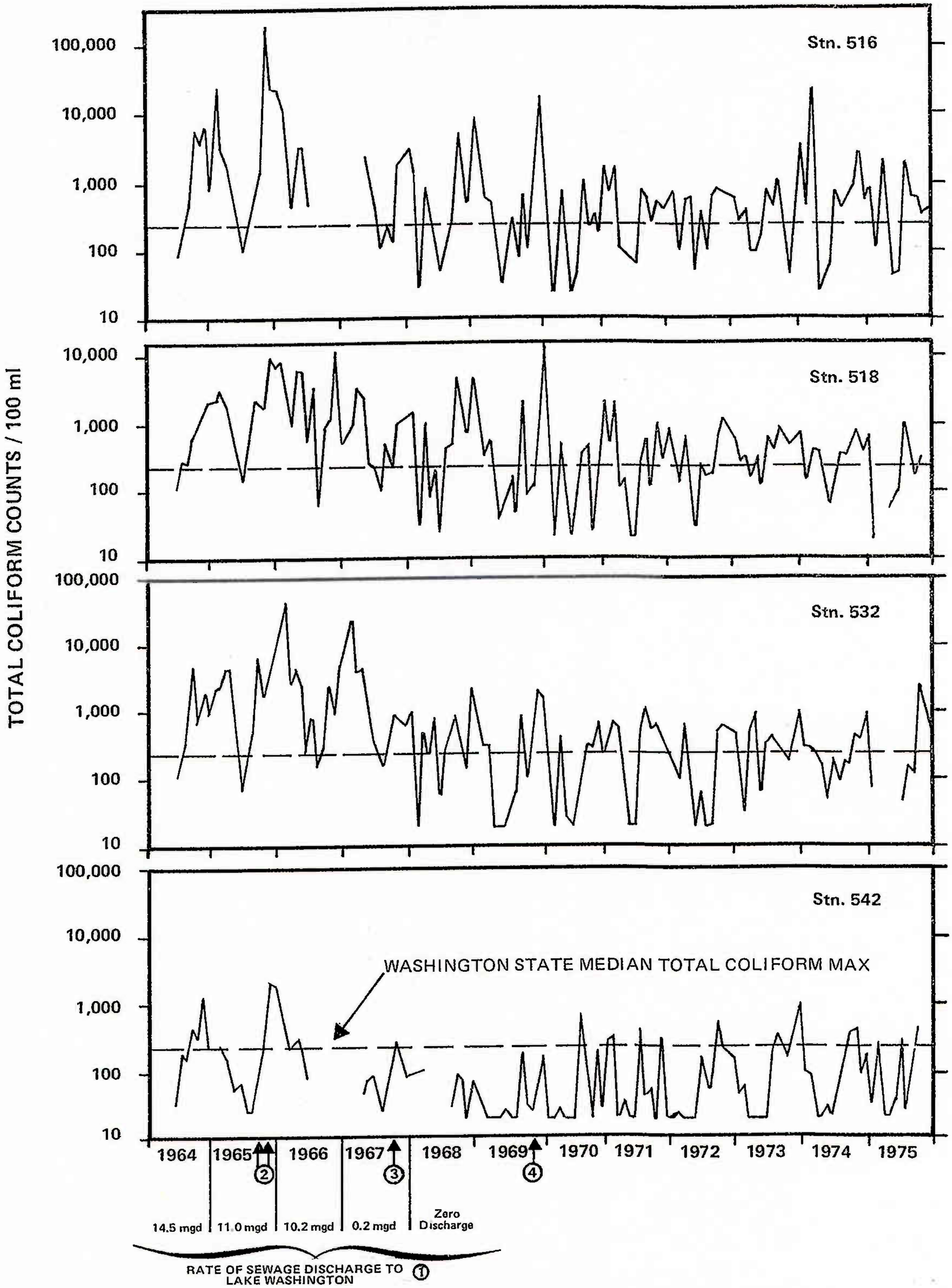


Fig. 4-16. Historical data on abundance of total coliforms in the Lake Washington Ship Canal. Significant sanitary engineering events: (1) sewage diversion from Lake Washington, (2) north trunk sewer by-pass, (3) change from multiple tube to membrane filter technique for coliform estimates, (4) Montlake siphon cleaned. Refer to Fig. D-1 for station locations.